11th International Motorcycle Conference
Cologne, 3-4 October 2016

Design of a novel tilting electric four-wheeler

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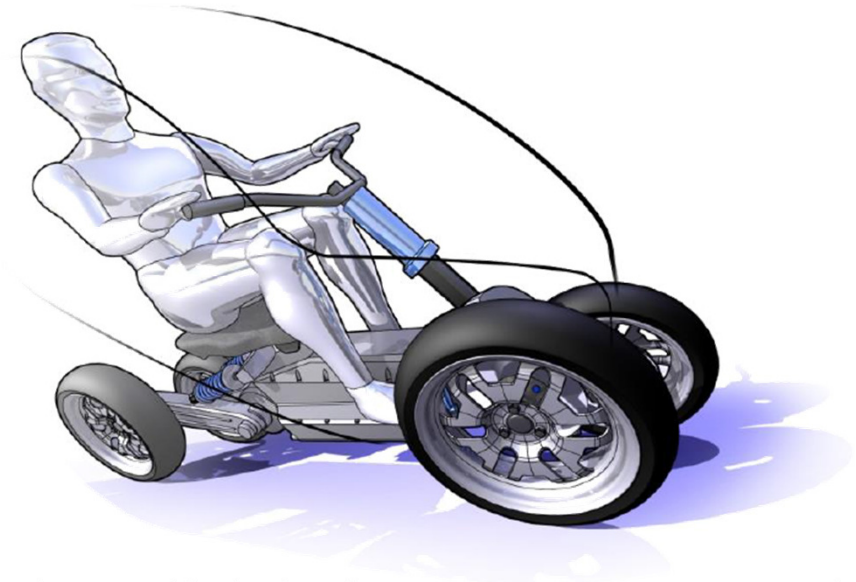
[b] AIT Austrian Institute of Technology GmbH, Wien, Austria
[c] Piaggio & C. Spa, Pontedera, Italy
[d] KTM Technologies GmbH, Salzburg/Anif, Austria



This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 653511

RESOLVE Project

Making light electric mobility an option

Horizon 2020 Program
Electric two-wheelers and new light vehicle concepts
(H2020-GV.5-2014)

Project Start
May 2015

Duration
36 months

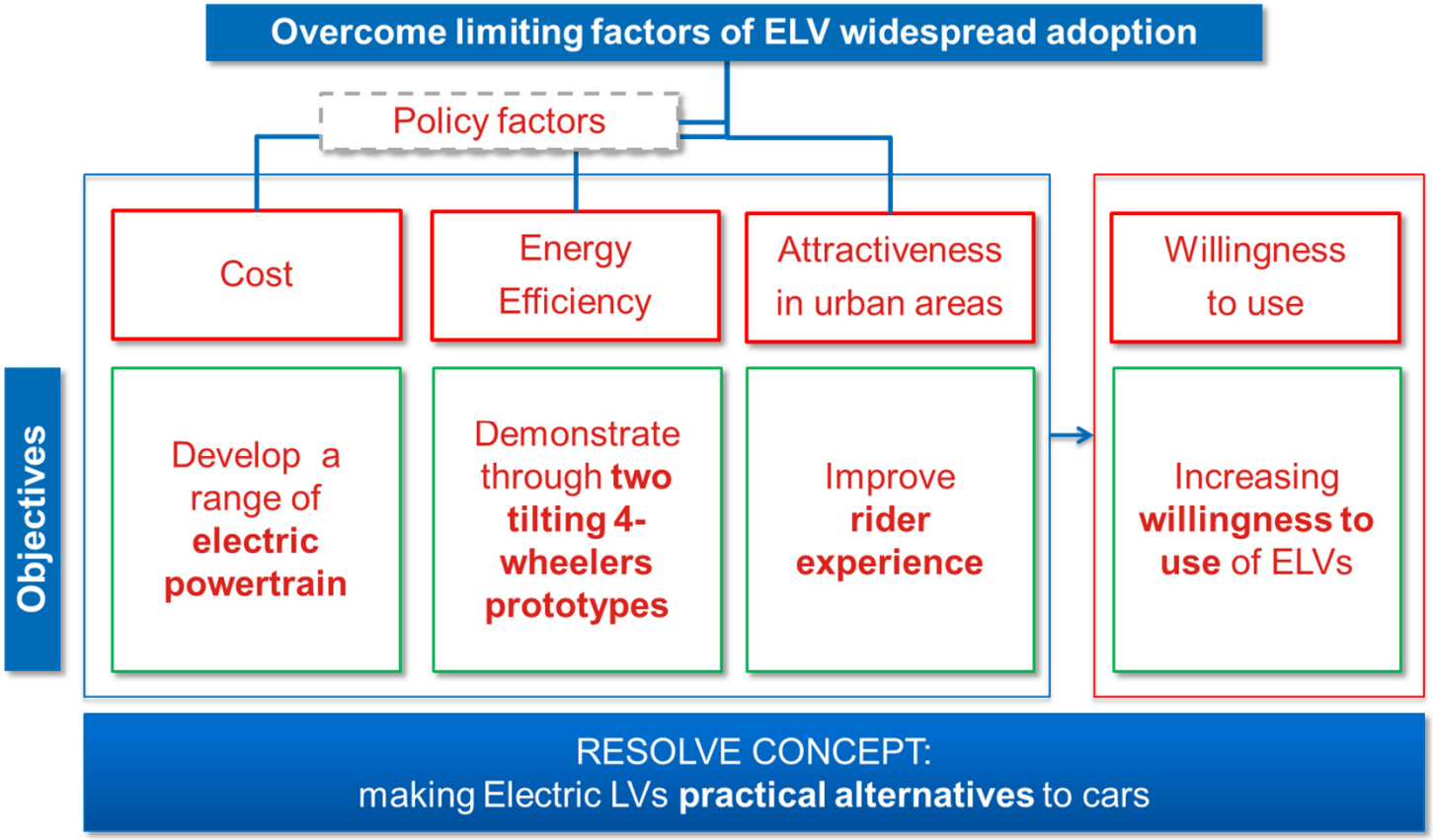
Project Coordination
Piaggio & C. S.p.A.

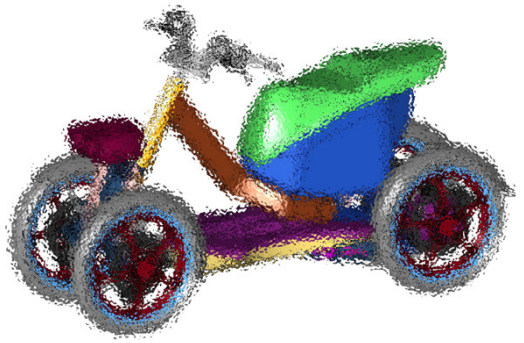
RESOLVE
RANGE OF ELECTRIC SOLUTIONS FOR L CATEGORY VEHICLES

EGVI
European Green Vehicles Initiative

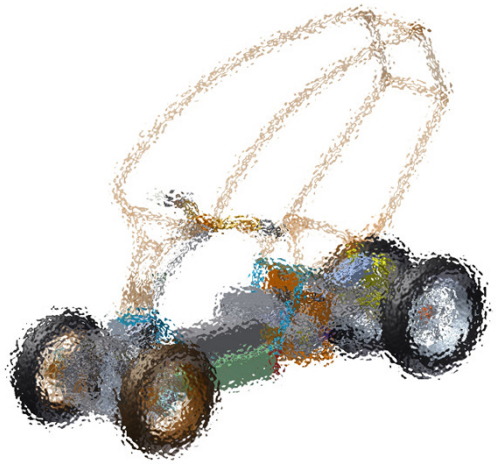
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 653511

Project Overview





Demonstrator 1 – L2



Demonstrator 2 – L6

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RESOLVE Consortium

Partners in alphabetical order

- AIT (A)
- IDIADA (SP)
- KTM (A)
- Piaggio (IT) - *coordinator*
- Ricardo (D)
- University of Pisa (IT)
- University of Warwick (UK)
- Bosch (D)
- KISKA (A)
- Marelli (IT)
- RE:Lab (IT)
- University of Firenze (IT)
- University of Prague (CZ)
- Wamtechnik (PL)

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Partners tasks

AIT (A)

- Longitudinal simulations
- Multibody simuations

University of Pisa (IT)

- Lateral dynamics simulations
- Finite element structural simulation
- Multibody simuations

KTM (A)

- Simulation workpackage coordination
- D2 Demonstrator design and construction

Piaggio (IT)

- Project coordination
- D1 Demonstrator design and construction

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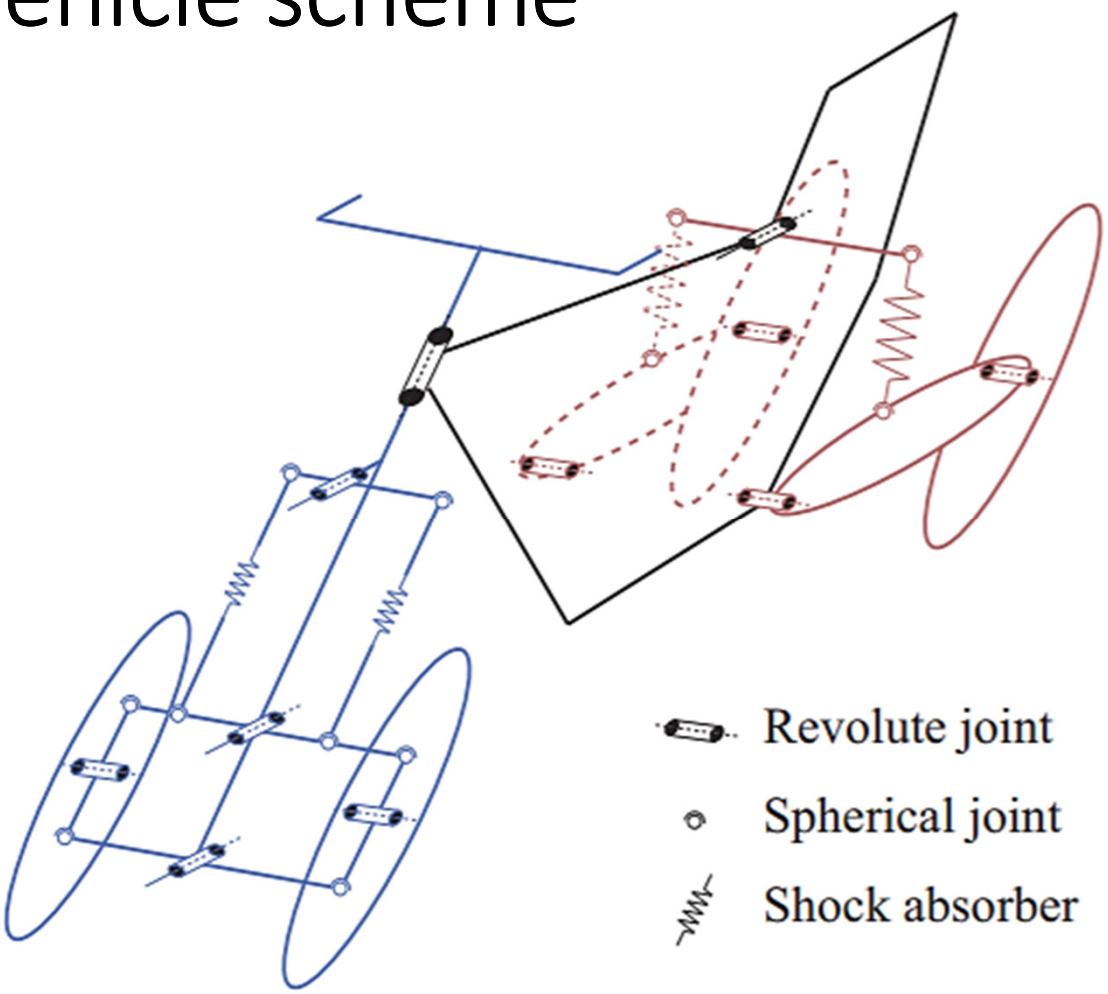
Vehicle scheme



- 2 steering front wheels operated by the handlebar
- 2 rear driving wheels
- 2 tilting lever (front and rear) which connect left and right wheels
- No roll stiffness
- Shock absorbers working in bumps

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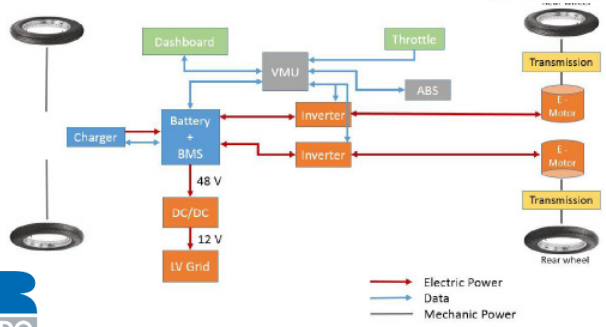
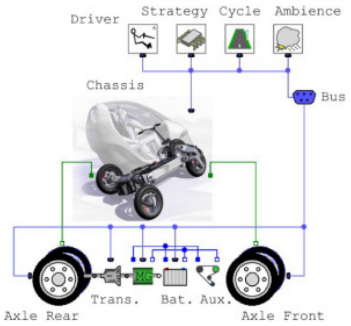
Design Outline

AUSTRIAN INSTITUTE OF TECHNOLOGY

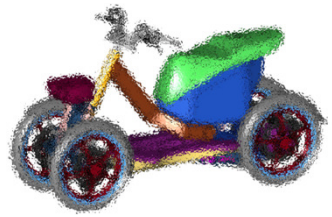


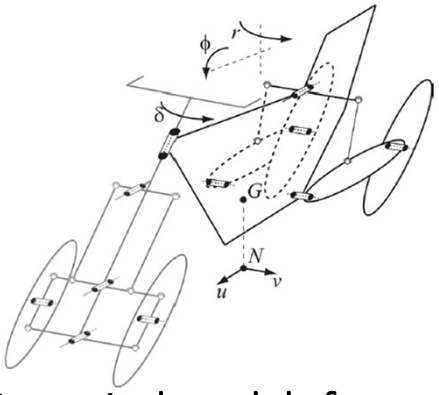
RICARDO

Powertrain architectures



Longitudinal dynamics





Numerical models for stability

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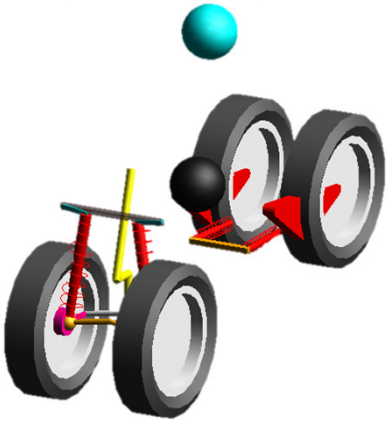

Multibody models for handling

Demonstrators (KTM and Piaggio)

EGVI European Green Vehicles Initiative

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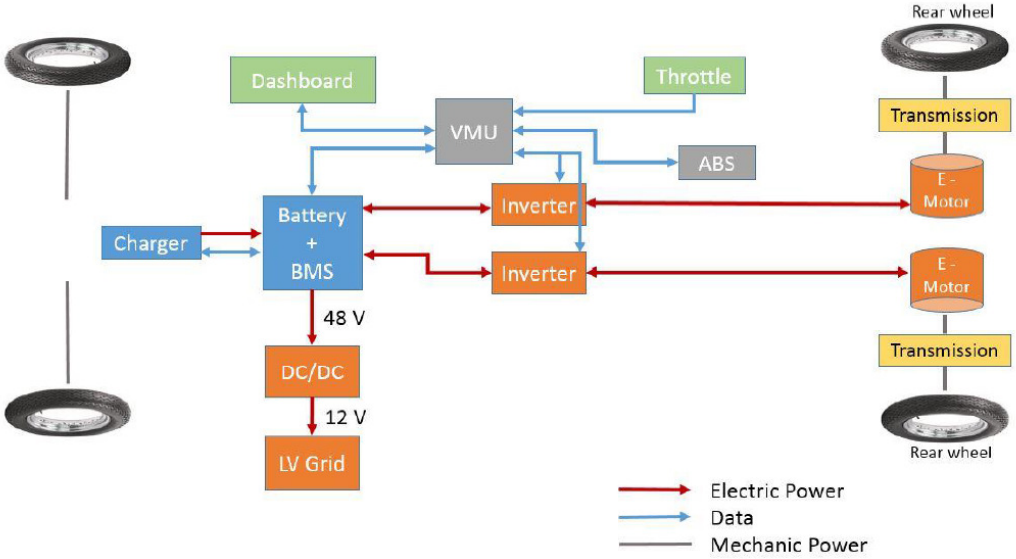
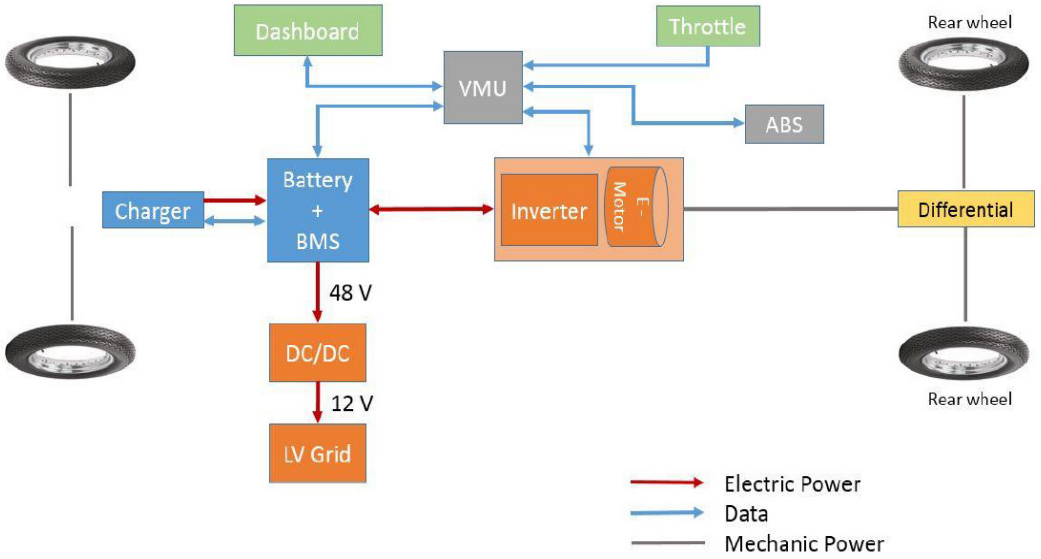
Powertrain schemes

Demonstrator 1



Demonstrator 2



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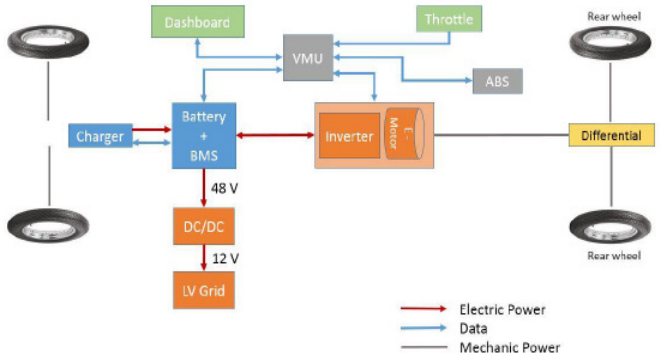
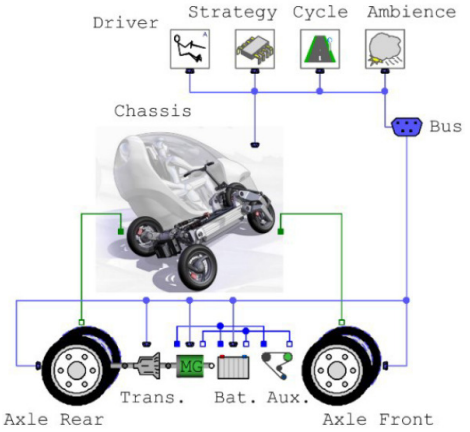
Longitudinal Dynamics



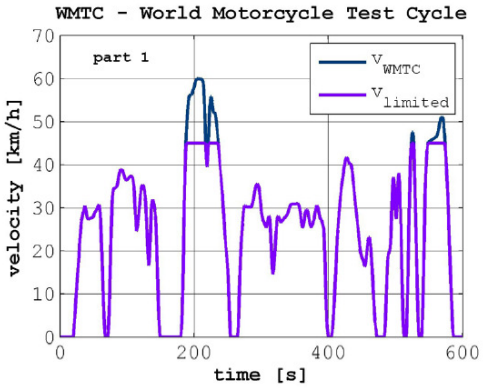


Choice of optimal gear transmission ratio

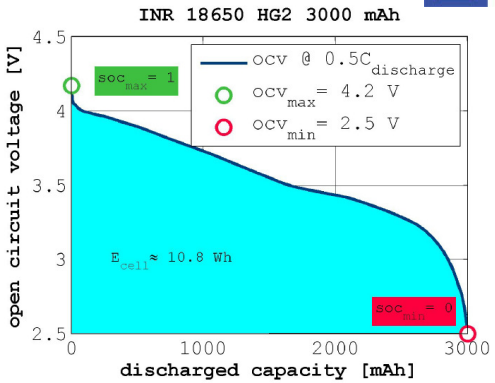
Energy consumption

Acceleration

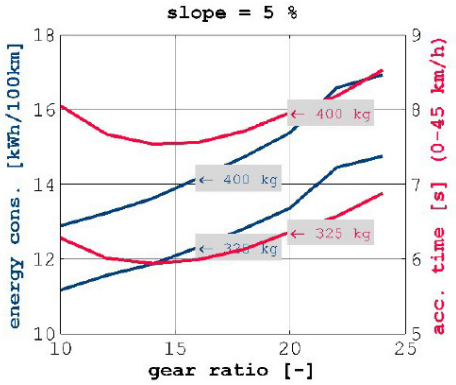
Dymola

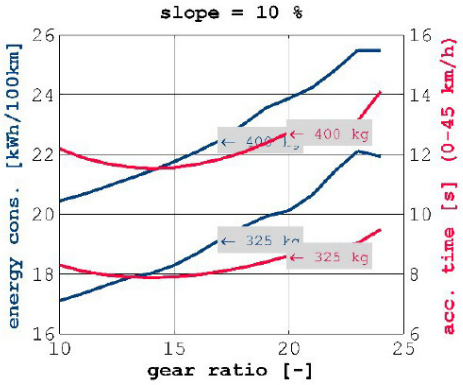


Reference Cycle (WMTC)



SOC estimator





Output values

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Stability and Dynamics

Why?

Assess the uncontrolled stability behavior of the vehicle and compare it with the natural stability behavior of 2-wheelers.

Does the rider perceive a similar vehicle behavior?

Literature fundamentals

THE STABILITY AND CONTROL OF MOTORCYCLES

By R. S. Sharp*

Mathematical models of a motorcycle and rider dependent on three alternative assumptions concerning the tyre behaviour are developed. Stability characteristics deduced from them are compared, and minimum requirements for the model greater than have been previously satisfied are established. Using the most sophisticated of the models, the effects of design changes are calculated, and the design implications are discussed.

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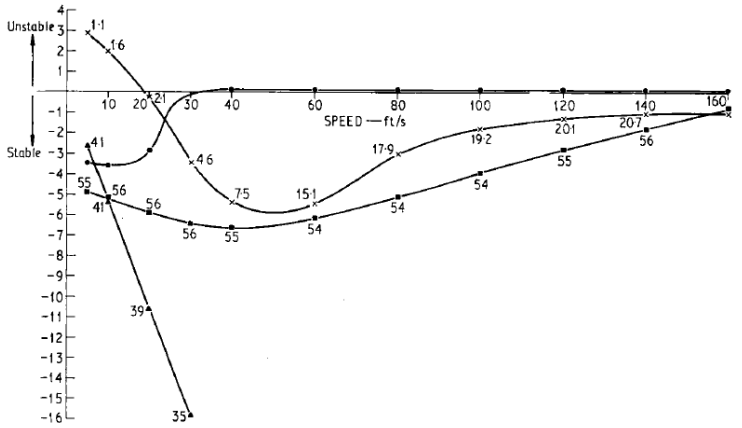

Fig. 5. *Stability and natural frequencies of standard machine as a function of forward speed with the full tyre treatment*

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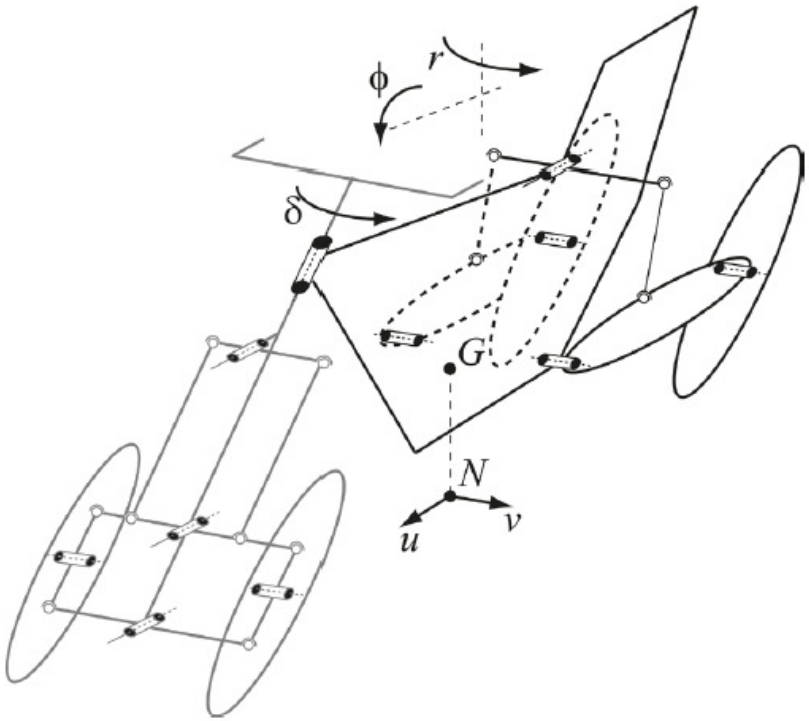
Stability and Dynamics

Numerical model



Hypotheses

- Rigid bodies
- Flat and horizontal road
- Locked suspensions
- Rigid and lenticular wheels
- Linear tire behavior

State variables

- Longitudinal speed *u*
- Lateral speed *v*
- Yaw rate *r*
- Steering angle δ
- Roll angle Ø

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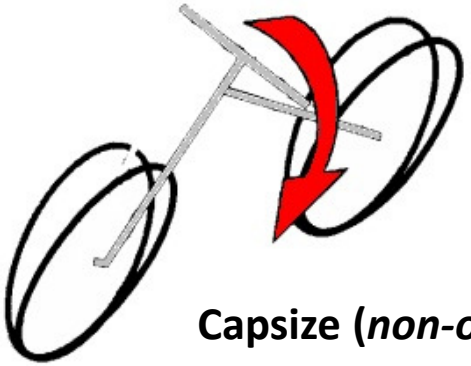
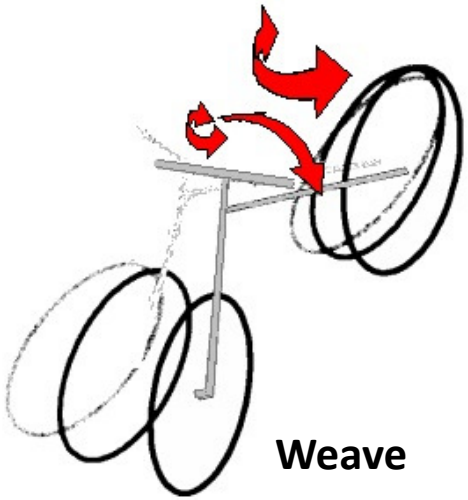
Stability and Dynamics

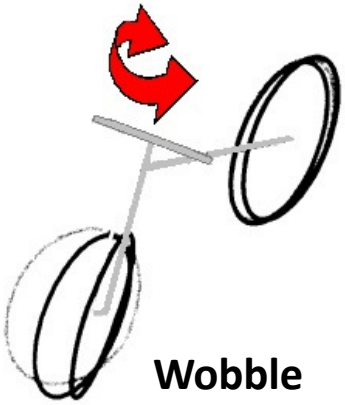
Natural modes



Capsize (*non-oscillatory*)



Weave



Wobble

Schemes from http://www.warious.pl/dynamika-motocykli/tryby-drgan/

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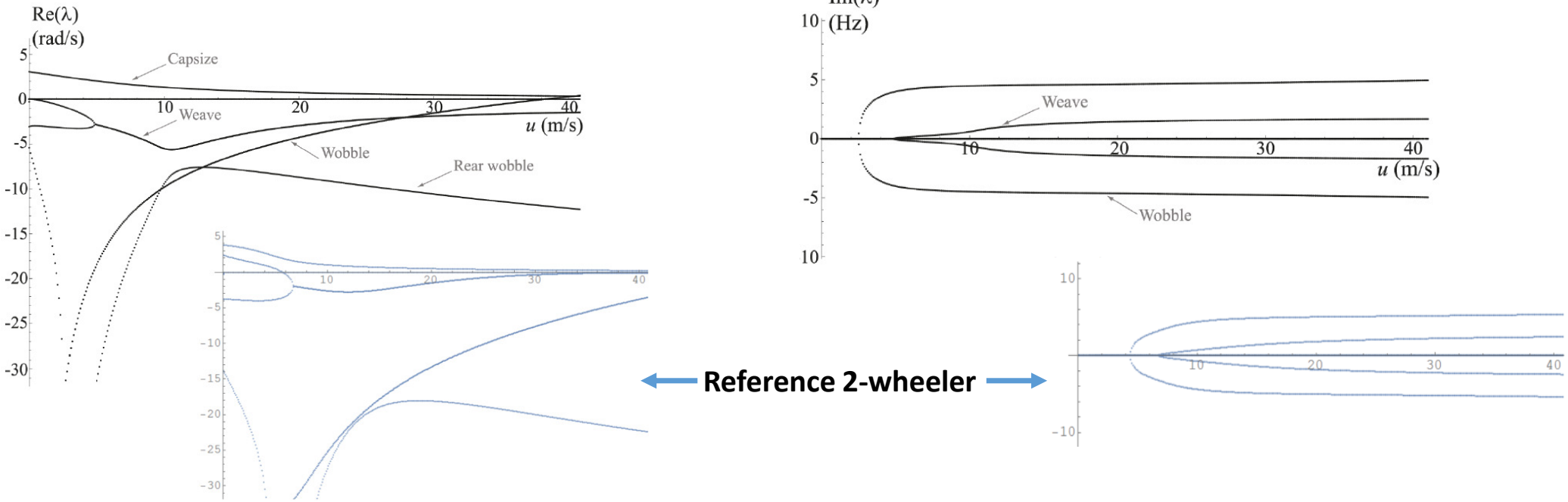
Stability and Dynamics

Natural modes



Reference 2-wheeler

Natural modes behavior similar to classical 2-wheelers and 3-wheelers → Similar rider perception

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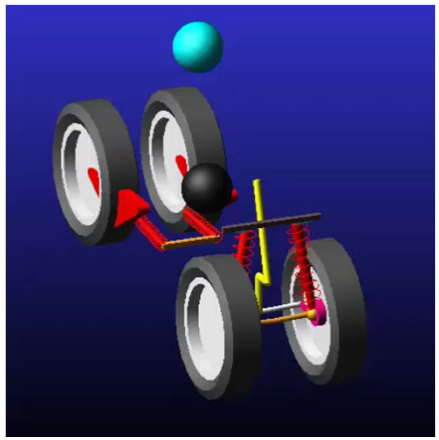
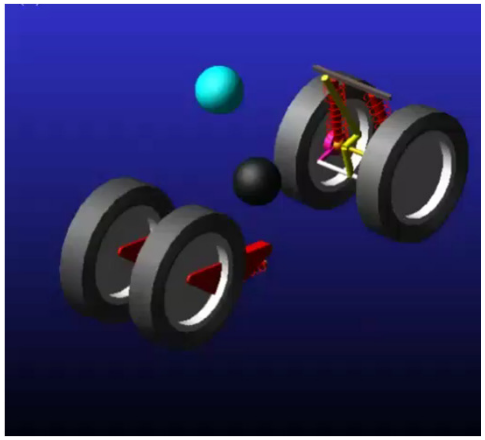
Stability and Dynamics

Natural modes with suspensions

In-phase motion of the front and rear wheels → Same design criteria of 2-wheelers





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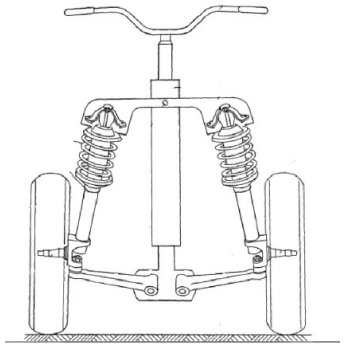
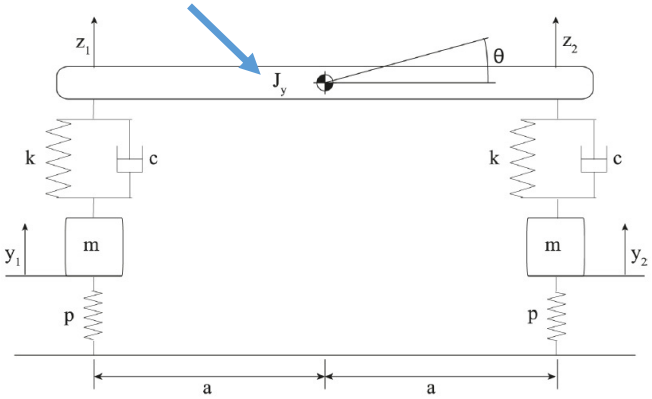
Stability and Dynamics

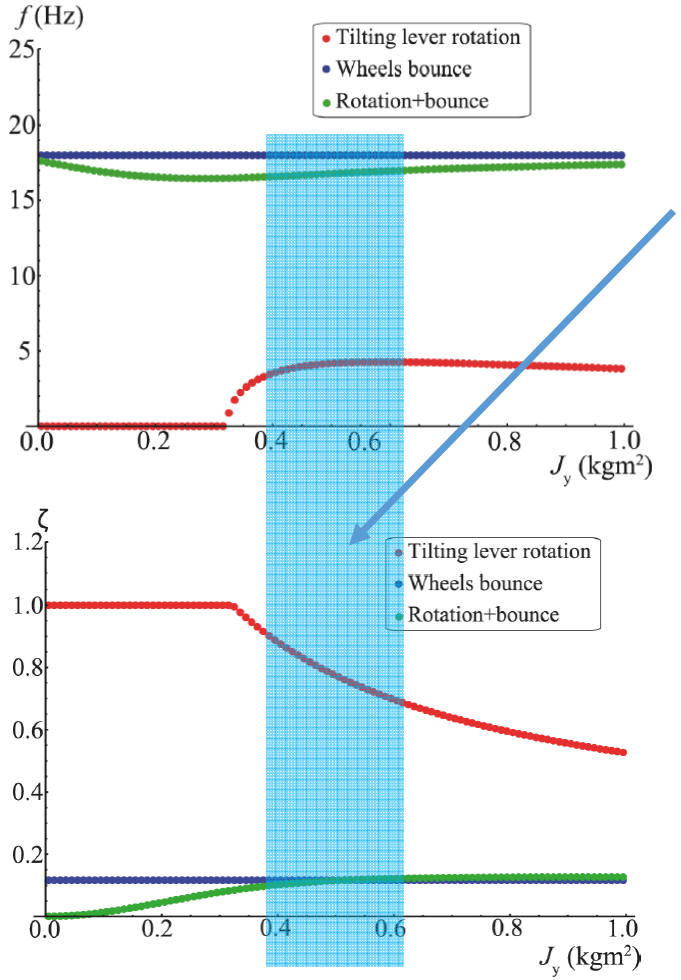
Tilting mechanism dynamic model



Tunable lever inertia



$$\boldsymbol{M\ddot{w} + C\dot{w} + Kw = 0} \quad \text{con} \quad \boldsymbol{w} = (\theta(t), y_1(t), y_2(t))$$



Optimal range of lever inertia

Alternatively: active control of suspensions

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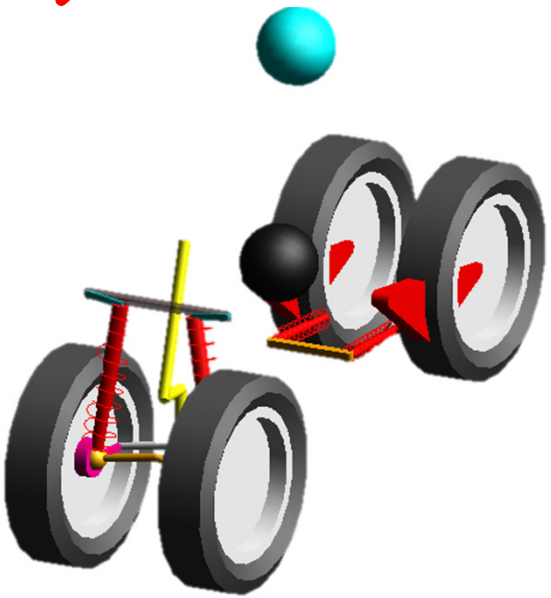
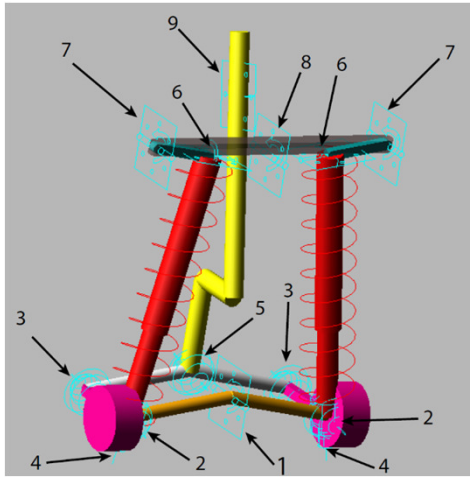
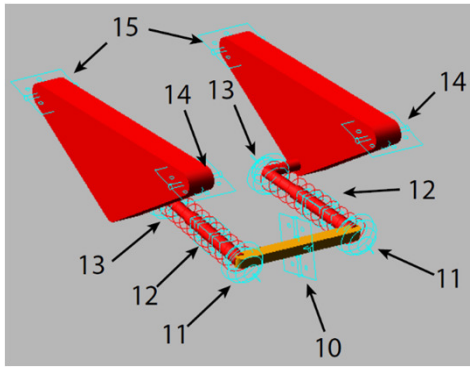
Multibody model



Vehicle model



Front tilting mechanism



Rear tilting mechanism

Virtual rider

Steering law: roll-angle follower

$$\dot{\delta} = k_1\ddot{\phi} + k_2\dot{\phi} + k_3(\phi_t(t) - \phi(t))$$

PID controller on target roll ange rate

Drive torque law: speed follower

$$T_{21} = \int_0^{\bar{t}} c_1(u_t(t) - u(t))\,\mathrm{d}t + c_2(u_t(t) - u(t)) + k(t)$$

$$T_{22} = \int_0^{\bar{t}} c_1(u_t(t) - u(t))\,\mathrm{d}t + c_2(u_t(t) - u(t)) - k(t)$$

PI controller on target longitudinal speed

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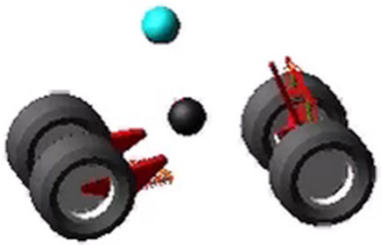
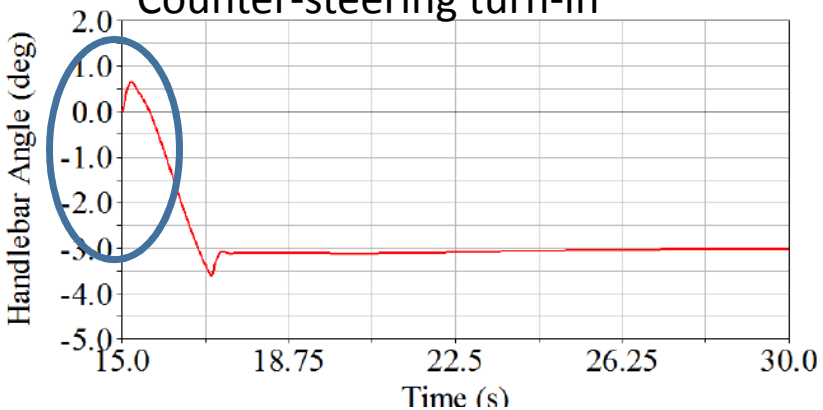
Multibody model - Exemplification maneuvers

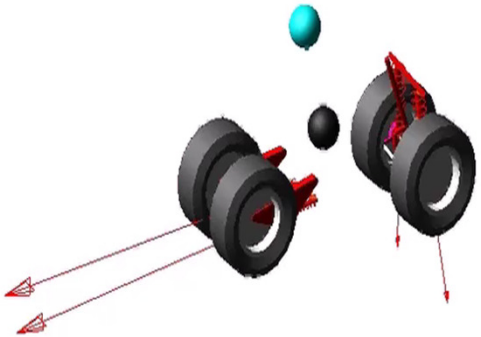
Steering pad

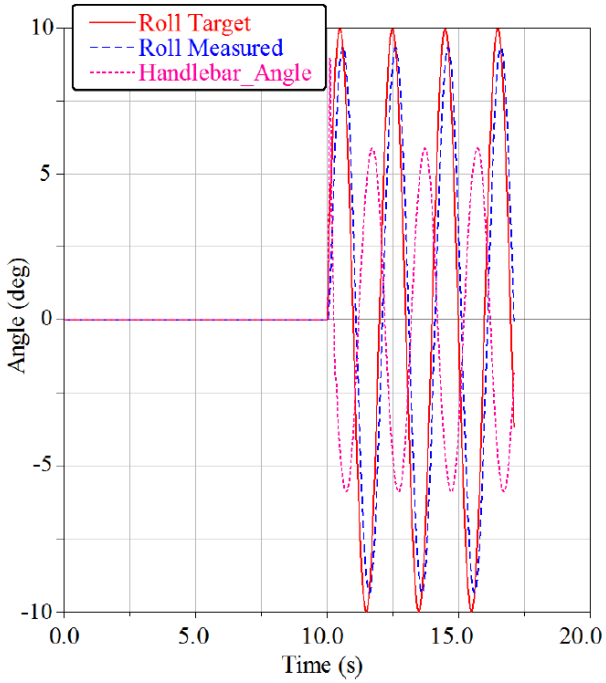


Counter-steering turn-in



Slalom





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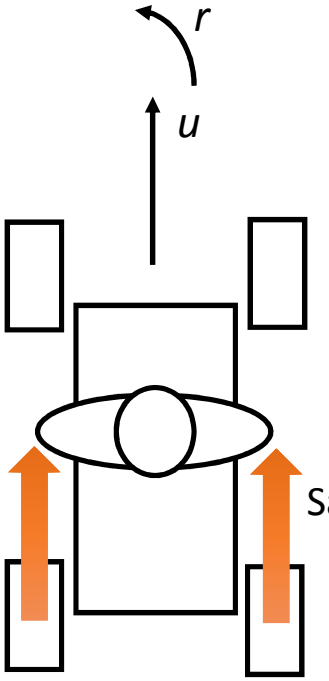
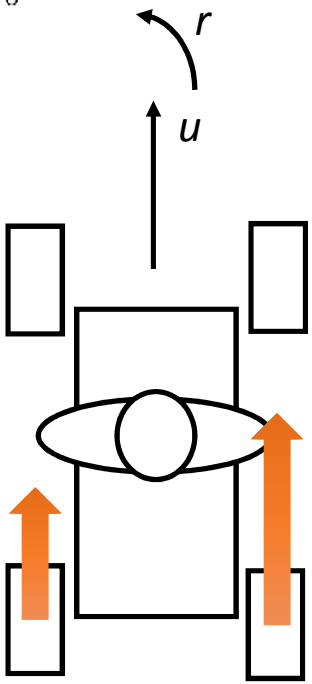
Rear drive torque – Yaw control

$$T_{21} = \int_0^{\bar{t}} c_1(u_t(t) - u(t))\,\mathrm{d}t + c_2(u_t(t) - u(t)) + k(t)$$

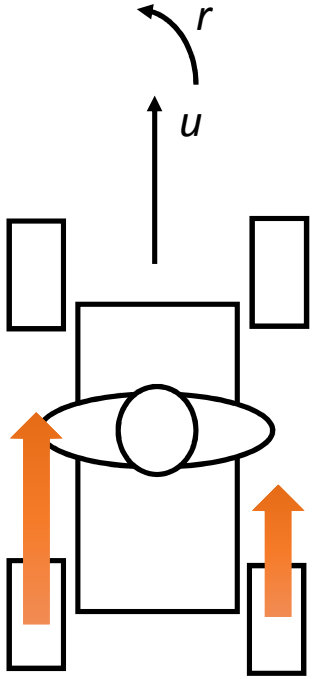
$$T_{22} = \int_0^{\bar{t}} c_1(u_t(t) - u(t))\,\mathrm{d}t + c_2(u_t(t) - u(t)) - k(t)$$



k=0
Same driving forces



k>0
Driving forces induces yawing torque



k<0
Driving forces induces counter-yawing torque

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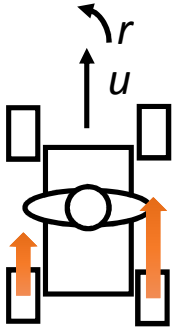
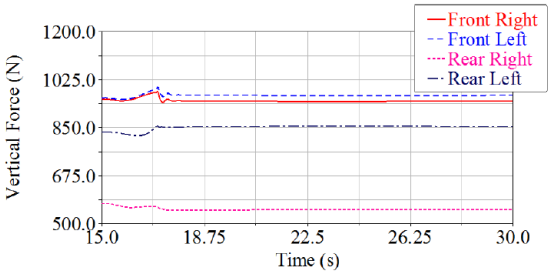
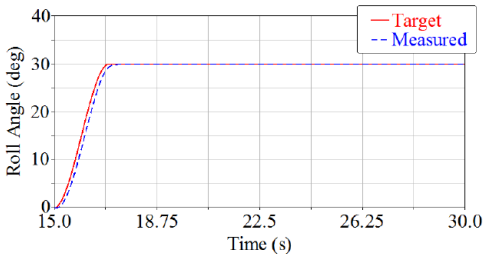
Rear drive torque – Yaw control

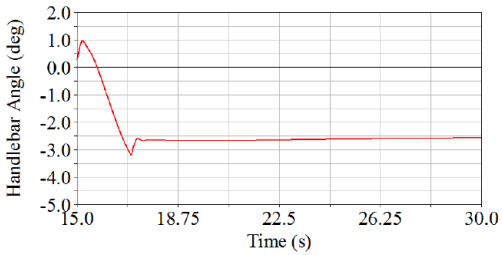
… torque control for ride assistance
… safe stabilizing aid in case of fall



Yawing torque

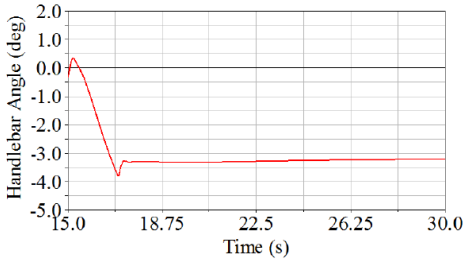




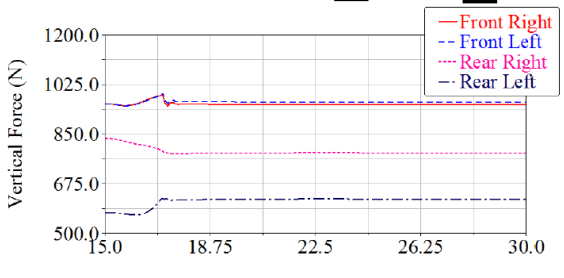


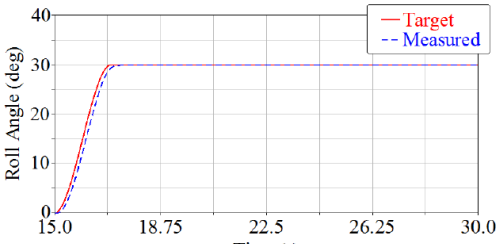
Same roll angle

Different load transfer and handlebar angles



Counter-yawing torque





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Conclusions

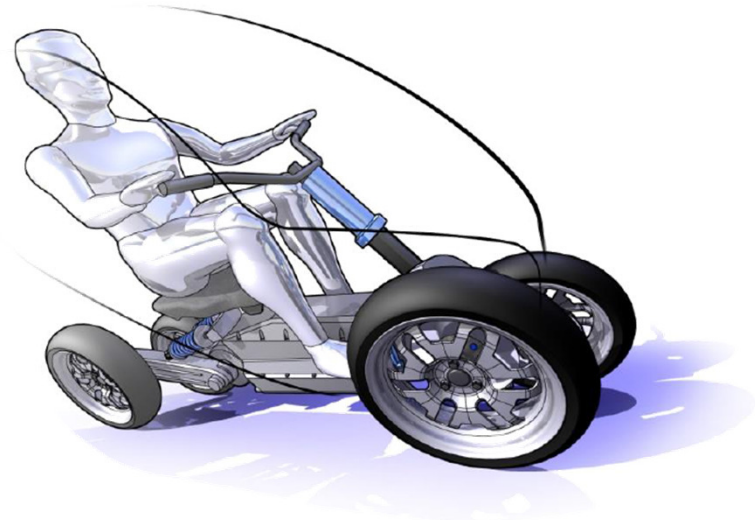
- Aim of the project: make electrical L-cathegory vehicles a valuable option
- Safe and enjoyable ride experience perception
- Modular and cost effective powertrains development
- Dynamic simulations to reproduce motorcycle-like riding behavior
- Possibility of torque and tilting control to aid rider and improve safety

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 653511

RESOLVE

RANGE OF ELECTRIC SOLUTIONS FOR L CATEGORY VEHICLES

Thank you for your attention



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